

# EARLY ORDOVICIAN ACRITARCHS FROM SOUTHERN JILIN PROVINCE, NORTH-EAST CHINA

by F. MARTIN and YIN LEIMING

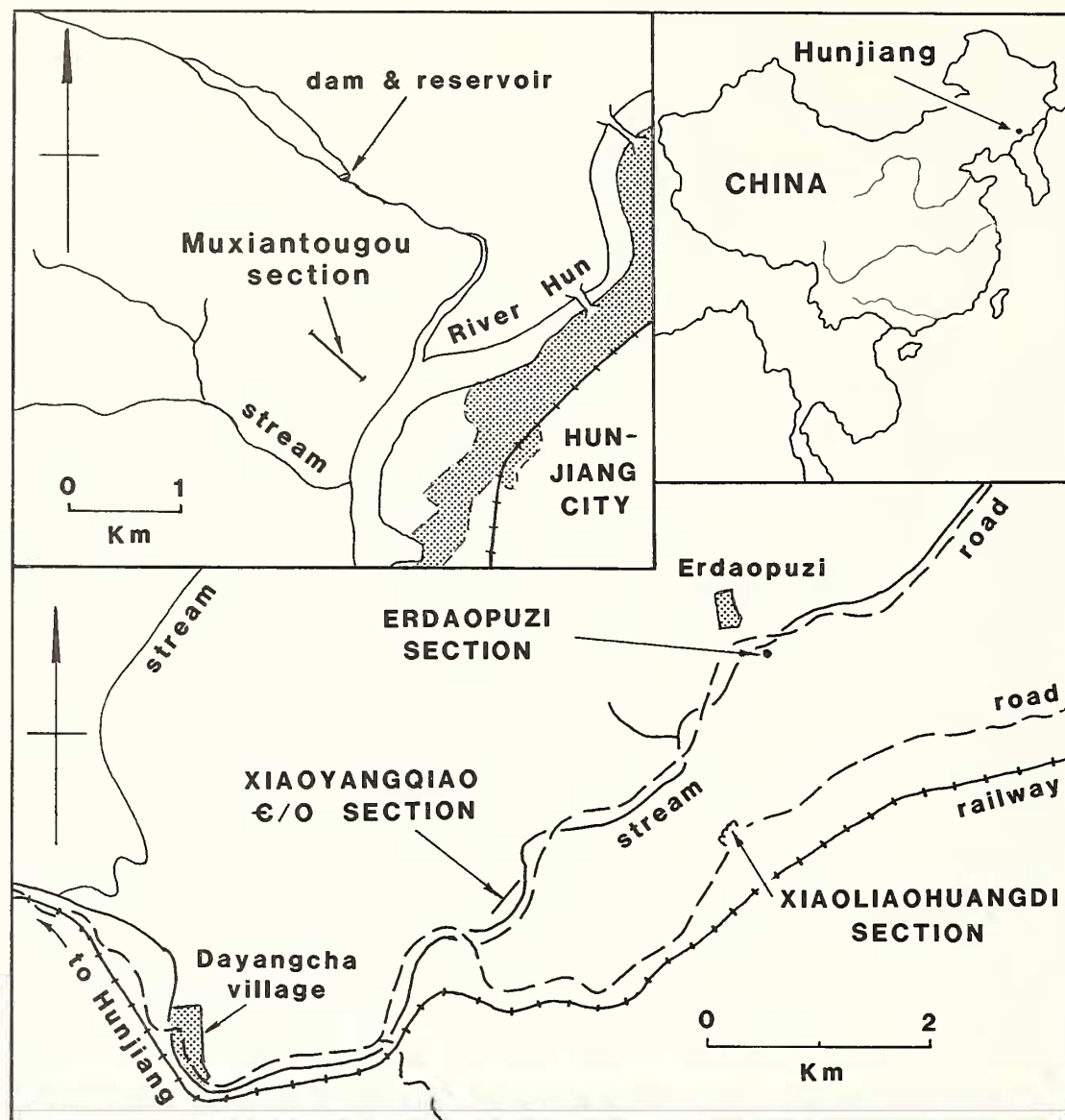
**ABSTRACT.** Preliminary sampling of early Ordovician deposits in the Hunjiang region, southern Jilin Province, north-east China, yielded generally well-preserved acritarchs, the seven most characteristic species of which are described. The strata form part of the northern margin of the Sino-Korean platform and are dated by graptolites ranging from Tremadoc (= post *Rhabdinopora parabola* Biozone and excluding early Tremadoc) to latest Tremadoc or earliest Arenig (*Adelograptus-Clonograptus*, with *Kiaerograptus*, fauna). The appearance of *Rhopaliophora* Tappan and Loeblich, 1971 emend. Playford and Martin, 1984 is considered with reservation as marking the base of the latter interval. New taxa comprise two genera, *Aryballomorpha* and *Lua*, and two new species, *L. erdaopuziana* (type species) and *Athabascaella penika*. Other species of *Athabascaella*, *A. playfordii* Martin, 1984 (type species), *A. rossii* Martin, 1984, and *Aryballomorpha grootaertii* (Martin, 1984) comb. nov. (type species) are emended; all three taxa are known from the Tremadoc of Laurentia, in strata of the southern Canadian Rocky Mountains dated by trilobites as belonging to letter zones D and E of Utah and Nevada, USA.

STRATA of latest Cambrian and earliest Ordovician age are well exposed in the vicinity of the city of Hunjiang, in the south of Jilin Province, north-east China (text-fig. 1). They form part of the northern margin of the Sino-Korean Platform (see review in Huang *et al.* 1977; Zhang *et al.* 1984) and are rich in a variety of fossil groups, principally graptolites, trilobites, cephalopods, conodonts, and acritarchs. Palaeontological studies relating to the Cambrian-Ordovician boundary have been published by Kuo *et al.* (1982), Chen *et al.* (1983), Chen, Zhou *et al.* (1985), Chen, Qian *et al.* (1985), Chen (1986), Duan *et al.* (1986), and Wang and Erdtmann (1986), all of whom proposed correlations with regions outside China. Since 1985 research has been stimulated by the interest of the Cambrian-Ordovician Boundary Working Group (International Union of Geological Sciences; Commission on Stratigraphy) in the succession at Xiaoyangqiao, near the village of Dayangcha, situated about 50 km by road north-east of Hunjiang. The section, first reported by Kuo *et al.* (1982), has since been proposed (Chen, Qian *et al.* 1985) as a candidate for the global stratotype of the Cambrian-Ordovician boundary. Acritarchs at the systemic boundary have been studied by Yin (1985, 1986). Here we describe seven early Ordovician acritarch taxa, from the same area but younger than those documented by Yin (loc. cit.). The seven have been selected from about twenty taxa, the majority of which are new and related to the *Baltisphaeridium* group, *sensu* Downie (1973). Diacrodians and veryhachiids are absent.

## NOTES ON CORRESPONDING GRAPTOLITE AND CONODONT ZONATION

The acritarchs come from preliminary sampling by the authors in 1985 and 1986 of calcareous mudstones in the 'Yehli Formation' as used by Wang and Erdtmann (1986, p. 227). These deposits are dated with reference to two informal graptolite biozones, one of *Psigraptus* and the other of *Adelograptus-Clonograptus*, with *Kiaerograptus*, that are found, respectively, at Erdaopuzi and at Xiaoliaohuangdi, near Dayangcha. Palynological samples from Muxiantougou, near Hunjiang, are stratigraphically located with reference to one or other of these two biozones.

No palynological study has yet been published in China or elsewhere for either of these two graptolite biozones, and for present purposes the following approximate ages are provisionally accepted: *a*, *Psigraptus* biozone is probably late Tremadoc; *b*, biozone of *Adelograptus-Clonograptus*, with *Kiaerograptus*, is latest Tremadoc or earliest Arenig. Tentative correlation with the Tremadoc Series is discussed below.



TEXT-FIG. 1. Outline map showing position of sections cited in the text.

The oldest sample from the Muxiantougou section, at a level 36 m below that of *Psigraptus* and about 160 m above *Rhabdinopora parabola* (Bulman, 1954), is considered to be of Tremadoc (excluding early Tremadoc) age. As far as graptoloids may be used in defining the Cambrian-Ordovician boundary, *R. parabola* indicates a level close to the base of the Tremadoc, both at Dayangcha and elsewhere (Lin 1986; Erdtmann 1986).

Wang and Erdtmann (1986) indicated that the horizons with *Psigraptus* at Erdaopuzi, which contain notably *P. arcticus* Jackson, 1967, *P. lenzi* Jackson, 1967, and *P. jacksoni* Rickards and Stait, 1984, belong probably to the lower part of the upper Tremadoc. Since then B.-D. Erdtmann (pers. comm.) considers that, following a re-examination of the sections, the strata containing *Psigraptus* at Erdaopuzi and Muxiantougou belong to a much higher level in the uppermost Tremadoc.

However, Cooper (1979, text-fig. 2) proposed a correlation between Biozone La 1.5 (which contains *Psigraptus*) of the sequence at Lancefield, Victoria, Australia, with part of the Tremadoc succession in Shropshire, England (Stubblefield and Bulman 1927; Cowie *et al.* 1972) extending from the Transition Beds to the *Adelograptus* [*Clonograptus*] *tenellus* Biozone. In addition to north-eastern China and south-eastern Australia, beds with *Psigraptus* are known from the Yukon, north-western Canada (Jackson 1967, 1974) and southern Tasmania (Rickards and Stait 1984). The latter authors commented on the imprecisely known position of *Psigraptus* within the Tremadoc; its oldest known appearance is in Biozone La 1.5 in Victoria (Cooper 1979), just above Biozone La 1, which is correlated with the *Rhabdinopora flabelliformis* Biozone, from the lower part of the Tremadoc in Shropshire. On the other hand Webby *et al.* (1981) correlated Biozone La 1 with the lower limit of the upper part (not defined in terms of macrofossils) of the Tremadoc in the British standard series. Although the terms lower and upper Tremadoc are sometimes used, they have not been formally defined. Erdtmann (1982, fig. 1) drew the 'Lower/Upper' Tremadoc boundary above the occurrence of *R. flabelliformis* (Eichwald, 1840) and below that of *A. tenellus* (Linnarsson, 1871), an interpretation that would restrict 'Lower' Tremadoc approximately to the lowest of the four biozones recognized in England and Wales by Cowie *et al.* (1972). This lack of agreement on formal subdivision of the Tremadoc justifies the choice of 'probably late Tremadoc' to denote the age of palynological samples from within or near the *Psigraptus* horizons.

According to Wang and Erdtmann (1986) the *Adelograptus*–*Clonograptus*, with *Kiaerograptus*, horizons in southern Jilin Province belong to the highest Tremadoc or lowest Arenig, or even an intermediate series, and would correspond to the lower part of the 'Hunneberg Stage', proposed originally as a substage of the Latorpian Stage in Sweden (Tjernvik and Johansson 1980). In Sweden the basal 'Hunneberg' interval has yielded North Atlantic Province conodonts of the *Paroistodus proteus* Biozone; the latter is lowest Arenig according to Lindström (1971), but for Bergström (1977) it occupies an intermediate position between the Tremadoc and the Arenig. Hunneberg strata are unrecorded from Wales and Shropshire, and formal assignment of the stage to one or other series will depend on future decisions by the IUGS.

Wang and Erdtmann (1986) emphasized the equivalence of the *Adelograptus*–*Clonograptus*, with *Kiaerograptus*, horizons in north-eastern China to the graptolitic 'Biozone La 2' in the Lancefield section, Australia, proposed by Cooper (1979) and placed by him at the summit of the Tremadoc. Conodont data have not yet been published in relationship to the strata with graptolites and palynomorphs at Xiaoliaohuangdi and Muxiantougou. C. R. Barnes (pers. comm.) indicates, on the basis of a limited and not precisely diagnostic conodont fauna containing *Tripodus laevis* Bradshaw, 1969 and *Paroistodus originalis* (Sergeeva, 1963), that one sample from 1.5 m above the *Adelograptus*–*Clonograptus*, with *Kiaerograptus*, level at Xiaoliaohuangdi is basal Whiterock in North American terms. In relationship to the British Arenig, Ross *et al.* (1982) correlated the base of the Whiterock, a recommended and provisional series in the USA, with a level within the *Didymograptus nitidus* Biozone (considered a Sub-biozone of the *D. extensus* Biozone by Whittington *et al.* 1984). In Canada Barnes *et al.* (1981) equated the base of the Whiterock with a level slightly below the base of the *D. hirundo* Biozone.

## LOCATION OF PALYNOLOGICAL SAMPLES

### 1. SANCHAZI 1:50,000 topographic map.

(a) Erdaopuzi section (= Section JD-32 in File 1985 of Nanjing Institute of Geology and Palaeontology, Academia Sinica (NIGPAS)).

References: Zhao and Zhang Shunxin 1985; Zhang Junming in Chen 1986, text-fig. 2.

Sample ER-6. 5.8 m below first (= lowest) *Psigraptus* level.

Sample ER-32. Second *Psigraptus* level, 7.3 m above ER-6.

Sample ER-3. Third *Psigraptus* level, 2.1 m above ER-32.

(b) Xiaoliaohuangdi section (= section HDA-36 in File 1986 of NIGPAS).

Reference: Chen *et al.* 1983, p. 5, loc. 2.

Samples XIA-1 and XIA-2. 3.0 m and 1.0 m, respectively, below the base of the *Adelograptus*–*Clonograptus*, with *Kiaerograptus*, level.

Sample XIA-34. Base of *Adelograptus*–*Clonograptus*, with *Kiaerograptus*, level, 1.0 m thick.

Samples XIA-3, XIA-4, and XIA-5. 1.1 m, 2.0 m, and 3.0 m, respectively, above XIA-34.

### 2. HUNJIANG 1:50,000 topographic map.

Muxiantougou section (= section HMD in File 1986 of NIGPAS).

Reference: Chen, Zhou *et al.* 1985, south-eastern end of section D, p. 3; text-fig. 2. Additional information concerning the upper part of the succession has been given to us by Lin Yaokun and Zhang Junming (pers.



comm.), who also used unpublished data furnished by Zhao Xianglin, discoverer of graptolites at the Muxiantougou section.

Sample MUX-10. Estimated 36.0 m below *Psigraptus* level (= HMD-169) and 160.0 m above *R. parabola* level (HMD-54).

Sample MUX-104. Topmost level with *Psigraptus* (= HMD-193).

Samples MUX-15 and MUX-105. Approximately 14.0 m above *Psigraptus* level and 5.5 m below first *Adelograptus-Clonograptus*, with *Kiaerograptus*, level (= HMD-201).

## MATERIAL AND METHODS

All samples were processed in the Department of Palaeontology, Institut Royal des Sciences Naturelles de Belgique (IRScNB), Brussels. Approximately 50 g of each of the thirteen samples of calcareous mudstone were treated using routine laboratory techniques. The organic residues were sieved by means of a metallic (54  $\mu$ m mesh) and a nylon filter (10  $\mu$ m mesh); treatment with zinc bromide (density 2.1–2.2) followed the filtration. Small portions of some residues were oxidized with pure nitric acid for 20 to 260 min. Preparation for scanning electron microscope (SEM) examination followed the method described by Playford and Martin (1984, pp. 189–190). The acritarchs are generally better preserved at Erdaopuzi and Xiaoliaohuangdi than at Muxiantougou, where they are often more fragmentary and darker, with more or less parallel fissures that result from compression in the sediment. However, in all the samples treated the colour of examples of the same species may vary from light yellow to more or less dark brown within a single slide, whether the residue had been oxidized or not. The frequent, preferential darkening of the vesicle and bases of the processes is a consequence of the thermal alteration that affects the acritarchs within a single assemblage very variably. Their preservation in southern Jilin Province indicates a slight to moderate diagenesis that is generally approximately equal to Stade N2–N3 of Correia (1967). The acritarchs are rare to moderately abundant, from about 10 to 200 specimens per g of rock. Chitinozoans are very rare (about 5 per g of rock), brownish, always incomplete, and present only in the highest strata related to the biozone of *Adelograptus-Clonograptus*, with *Kiaerograptus*, at Xiaoliaohuangdi, and they are only mentioned in the subsequent discussion. Figured specimens, all mounted in Canada balsam, are deposited in the type fossil collection of the NIGPAS; supplementary slides are housed in the Department of Palaeontology at the IRScNB.

## SYSTEMATIC PALAEOLOGY

Group ACRITARCHA Evitt, 1963

Genus ARYBALLOMORPHA gen. nov.

*Type species.* *Aryballomorpha grootaertii* (Martin) comb. nov. et emend.; here designated; described below.

*Etymology.* Greek, *aryballos*, purse; *morphos*, form.

*Diagnosis.* Vesicle globular in both polar and lateral views. Oriented laterally, most specimens show prominent, apical tubular extension with circular, distal opening. No evidence of operculum. External surface psilate to echinate. Numerous flexible processes distributed evenly over all surface except that of tubular extension. Each process cylindrical or slightly conical, hollow; exceptionally interior communicates with that of vesicle, but otherwise the two are separated by continuation of vesicle wall. Distal extremity of each process divided into narrow straps that anastomose with those of neighbouring processes to form delicate, peripheral network with fine, dense mesh.

*Discussion.* The number of wall layers of the vesicle is not stated in the diagnosis; in most cases there is apparently a single layer, but exceptionally a double layer is observable locally at the base of a damaged tubular extension. Within a single slide the colour of the vesicle is generally darker than that of the processes. However, certain specimens are entirely transparent, even in material unoxidized with nitric acid, and in these cases the membrane of the vesicle has a thickness apparently identical with that of the processes. *Aryballomorpha* is distinguished from *Aremoricanium* Deunff, 1955 by the distal ramifications of the processes, which form a network or reticulum surrounding the vesicle. As stated by Jacobson and Achab (1985, p. 171) the latter genus, recorded from Arenig to Llandovery, is in need of revision, for the species included in it by Loeblich and MacAdam (1971) vary considerably



in both the general form of the central body and the ornamentation and number of vesicle layers. In particular an SEM revision of *A. tosotrichion* Loeblich and MacAdam, 1971 may show it to belong to *Aryballomorpha*. This species, which occurs in the Middle Lake Member (?Llandeilo to early Caradoc) of the Bromide Formation in Oklahoma, USA has, according to its original diagnosis, a vesicle covered with very fine, hair-like processes 'matted along the periphery'. The original, optical microscope illustrations (Loeblich and MacAdam 1971, pl. 19, figs. 1, 3, 4, 6, 7) do not permit the tips of the processes to be distinguished, and an SEM photograph of an entire specimen (op. cit., pl. 19, fig. 2) is too uneven for unambiguous interpretation. *Aryballomorpha* differs from *Tunisphaeridium* Deunff and Evitt, 1968 in having a distally open tubular extension and processes that are hollow, as opposed to apparently mostly solid, so that their interiors may communicate with the vesicle cavity.

*Aryballomorpha grootaertii* (Martin) comb. nov. et emend.

Plate 13, figs. 1–11; Plate 14, figs. 1 and 2

v 1982 Acritarch gen. et sp. nov. A Martin in Dean and Martin, p. 138, pl. 1, fig. 13.

v\* 1984 *Aremoricanium?* *grootaertii* Martin, p. 442, pl. 58.1, figs. 1–9; pl. 58.2, figs. 1–4.

*Type horizon.* Tremadoc of Alberta, Canada, between trilobite letter zones D and E in terms of the zonal succession established in Utah and Nevada, USA.

*Emended diagnosis* (based on 400 Chinese specimens). Vesicle originally spherical or almost so; outline circular to subcircular in both polar and lateral views. Oriented laterally, most specimens show prominent, variably protruding, apical tubular extension, which is hollow and has distal, circular opening. No operculum observed. Length and basal diameter of tubular extension usually, and respectively, from one-fifth to one-third, and from one-quarter to one-third, of diameter of vesicle. External surface of both vesicle and tubular extension psilate to variably echinate. Numerous homomorphic, flexuous, slender processes, usually one hundred or more on each face, evenly distributed over all surface except that of tubular extension, which tends to exhibit fine, longitudinal folds. Processes originally hollow, with interior assumed to have communicated originally with that of vesicle; more often the two are separated by continuation of vesicle wall. Processes proximally elongated, cylindrical to slightly conical with length from one-fifth to one-third of vesicle diameter. They are frequently ornamented with fine, longitudinal folds and were originally oriented perpendicular to surface of vesicle; distal extremity of each is divided into two to four straps that anastomose densely with those of neighbouring processes to form delicate, interwoven, peripheral meshwork.

*Dimensions* (based on one hundred specimens). Diameter of vesicle: 31 (48) 69  $\mu\text{m}$ ; length and basal width of tubular extension: 9.0–20.0  $\mu\text{m}$  and 14.0–24.0  $\mu\text{m}$ ; length and width of elongated, undivided part of processes: 12.0–27.0  $\mu\text{m}$  and 0.7–2.0 (usually 1.0–1.5)  $\mu\text{m}$ ; length of spines: 0.3–0.5  $\mu\text{m}$ , exceptionally 0.7  $\mu\text{m}$ ; thickness of vesicle wall: 0.2–0.3  $\mu\text{m}$ .

*Discussion.* A double membrane is rarely and locally observable on damaged tubular extensions; otherwise the vesicle wall is apparently single-layered. Preservation quality affects the ornamentation of the vesicle wall, the number of processes, and the appearance of their proximal internal cavity and their delicate, distal ramifications. Corrosion may eliminate the echinate ornamentation of the surface or produce a fine, irregular pitting that accentuates artificially the sculpture of the wall (Pl. 13, fig. 5). In abraded specimens, numerous processes have partly or entirely disappeared (Pl. 13, figs. 1, 3, 4). Transparent specimens may show locally the free communication between the proximal internal cavity of the processes and that of the vesicle; they may also show the process wall as thick as that of the vesicle. However, of fifty specimens observed with the SEM, none showed an orifice opening into the base of a process; on the contrary (Pl. 13, fig. 2) broken-off processes did not leave any scar on the wall of the vesicle. This apparent contradiction may eventually be explained as being due to secondary closure related to thermal alteration, being seen in transmitted light as the preferential darkening of the bases of the processes. It has not been observed whether or not the distal ramifications are solid. If

they are completely preserved, the density of the resulting interwoven, peripheral network masks the most proximal part of the processes under both the SEM and the optical microscope. In transmitted light certain opaque specimens appear to have processes shorter than those mentioned in the emended diagnosis; SEM examination shows that they have a proximal portion bent by compression and/or are not located on the outline of the vesicle. When the two faces of the same specimen are examined, one with the SEM and the other with the optical microscope, after mounting the gold-coated acritarch in Canada balsam, it appears that the tubular extension may either seem to be absent or be difficult to see because it is compressed. *A. grootaertii* differs from *Aremoricanium tosotrichion* in having processes that are both thicker and hollow, divided distally into fine, anastomosing straps.

Genus *ATHABASCAELLA* Martin, 1984 emend.

*Type species* (by original designation). *Athabascaella playfordii* Martin, 1984, redescribed below.

*Emended diagnosis.* Vesicle globular, with circular outline and apparently single-layered: external surface psilate or with minor sculpture. Processes numerous and well differentiated, the proximal part of each being originally hollow, its interior cavity communicating with that of vesicle. Processes divide distally to form distinct ramifications to third or fourth order; tips either very short, widening slightly and rounded, or elongated, thinning progressively distally. Slightly conical or more or less cylindrical lower parts of adjacent processes and their distal subdivisions may be joined by anastomosing lateral expansions. Delicate, transparent membrane, supported by distal parts of processes, may be present. Excystment opening in form of one rarely observed pylome.

*Discussion.* The diagnosis is emended principally to indicate that the processes are hollow proximally, that their internal cavities communicate with that of the central body, and that only their distal extremities support the very thin, peripheral membrane. Following alteration of the organic material, the processes are frequently rendered secondarily opaque and the lateral expansions linking them are broken; in the latter case the expansions persist in the form of fine, spine-like projections, principally at the level of the trunks of the processes. The peripheral membrane is not always preserved and is rarely found complete. Under the SEM it appears artificially, relatively thick. The total absence of the membrane may be either primary, linked to a particular stage of the life cycle, or secondary, the result of preservation. The pylome is rarely present, and then only in specimens that lack the peripheral membrane, an observation that suggests the presence, within a single taphocoenosis, of two different phases of the biological cycle.

*Athabascaella penika* sp. nov.

Plate 14, figs. 3–8

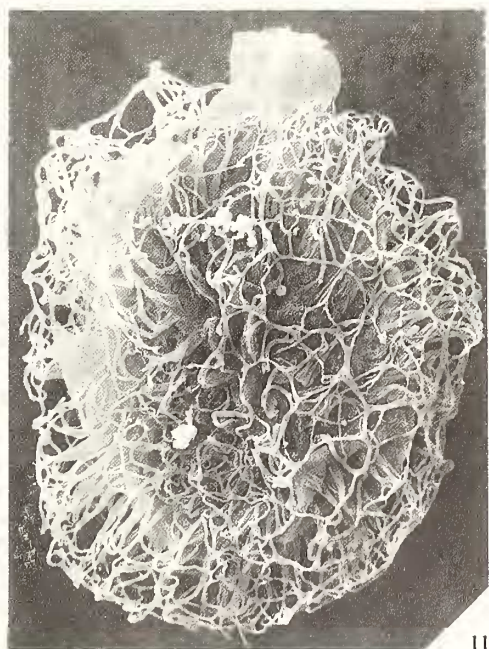
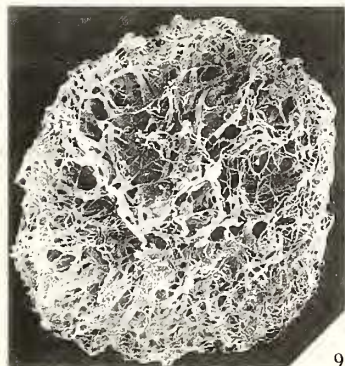
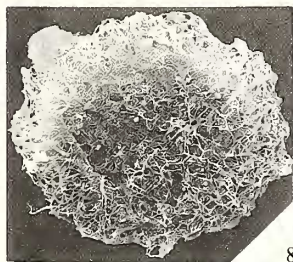
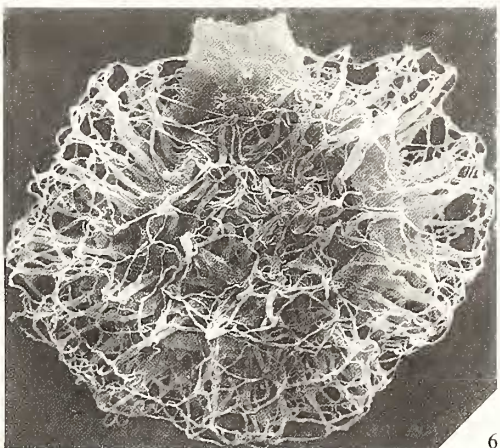
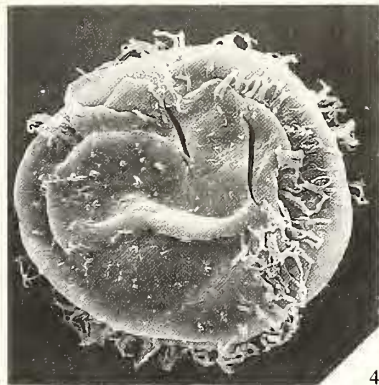
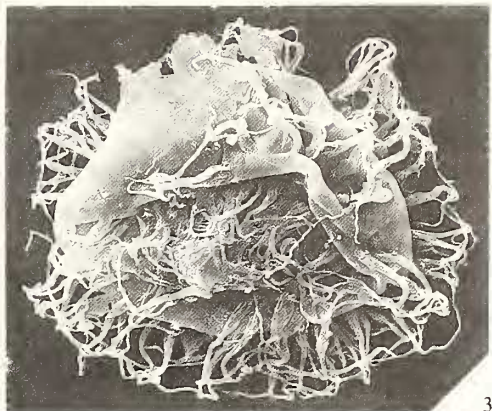
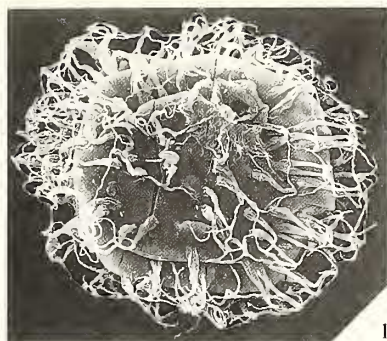
*Etymology.* Greek, *penika*, wig; by apposition.

*Holotype.* NIGPAS, M. and Y. slide 3, M-32; Plate 14, figs. 4 and 5. Vesicle globular, slightly compressed,

EXPLANATION OF PLATE 13

Figs. 1–11. *Aryballomorpha grootaertii* (Martin) comb. nov. et emend. 1 and 2, M. and Y. slide 11, N-32-4; MUX-10. 1, apical view with damaged tubular extension,  $\times 750$ ; 2, enlargement of longitudinally broken processes showing hollow internal cavity in lower median part of 1,  $\times 8000$ . 3 and 5, M. and Y. slide 11, O-32-2; MUX-10. 3, lateral view,  $\times 1000$ ; 5, enlargement of lower median part of 3,  $\times 4000$ . 4, M. and Y. slide 11, M-32-4; MUX-10; antapical view,  $\times 1000$ . 6, M. and Y. slide 3, K-32; ER-32; lateral view,  $\times 1000$ . 7 and 9, M. and Y. slide 4, K-45-1; ER-32. 7, enlargement of upper left part of 9,  $\times 4000$ ; 9, antapical view,  $\times 1000$ . 8, M. and Y. slide 2, O-38-4; ER-32; sublateral view,  $\times 500$ . 10 and 11, M. and Y. slide 2, P-39-3; ER-32; lateral view. 10, opposite face of gold-coated specimen of 11,  $\times 500$ ; 11,  $\times 1000$ .







40.0–46.0  $\mu\text{m}$  in diameter; length and basal width of trunks of processes: 5.0–12.0  $\mu\text{m}$  and 1.0–2.5  $\mu\text{m}$ ; length of distal subdivisions: up to 2.0  $\mu\text{m}$ .

*Type locality and horizon.* Erdaopuzi section, Jilin Province, north-east China; second *Psigraptus* level (Tremadoc Series) in 'Yehli Formation'. Sample ER-32.

*Diagnosis* (based on eighty specimens). Vesicle globular, with circular outline, and apparently single layered. External surface psilate to scabrate. About 100–150 well-differentiated, evenly distributed processes on each face. Proximal part of each, originally hollow with interior that communicates with that of vesicle, is elongated, more or less cylindrical to slightly conical; base is narrow and length from one-sixth to one-third, usually one-fourth, of vesicle diameter. Distal part of each process presents two to four squat, short subdivisions of first order, which are in turn generally subdivided up to second order, the tips being rounded and of variable width. Locally trunks and distal subdivisions may show lateral expansions that join adjacent processes. Delicate, transparent, peripheral membrane, supported by distal subdivisions of processes sometimes present. Presence of opening uncertain.

*Dimensions* (based on fifty specimens). Diameter of vesicle: 24 (45) 62  $\mu\text{m}$ ; length and basal width of trunks of processes: 5.0–15.0  $\mu\text{m}$  and 1.0–2.5  $\mu\text{m}$ ; length of distal subdivisions up to third order: 2.5  $\mu\text{m}$ ; vesicle wall thickness: less than 0.3  $\mu\text{m}$ .

*Discussion.* *Athabascaella penika* differs from *A. playfordii* in having processes whose ramifications are shorter, those of the first order being in the form of a rosette; and from *A. rossii* in having processes with relatively longer trunks. The distal curvature of the processes, which often have the form of a crook, is considered to be a secondary feature, the result of preservation.

*Athabascaella playfordii* Martin, 1984 emend.

Plate 15, figs. 7–11

v\* 1984 *Athabascaella playfordii* Martin, p. 444, pl. 58.3, figs. 1–9.

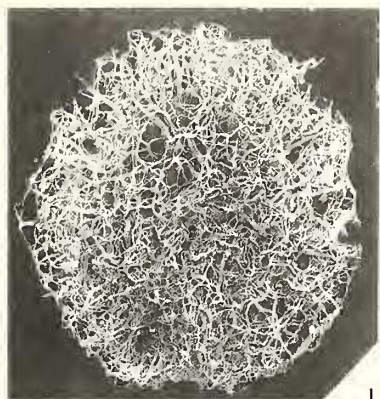
*Type horizon.* Tremadoc of Alberta, Canada, between trilobite letter zones D and E in terms of zonal succession established in Utah and Nevada, USA.

*Emended diagnosis* (based on eighty Chinese specimens). Vesicle globular with circular outline, and apparently single layered. About sixty to one hundred well-differentiated processes evenly distributed on each face; proximal part of each originally hollow and its interior communicates with that of vesicle. Lower parts of processes, sometimes joined by fine, lateral trabeculae, have more or less cylindrical to slightly conical, trunk-like form, with narrow base and length between one-seventh and one-third diameter of vesicle. Distal extremities of processes ramify, generally from same level, into two or three divisions, themselves subdivided distinctly to third or fourth order. Tips prolonged as fine, reticulate filaments that anastomose with those of adjacent processes. Circular pylome, rarely seen, always compressed with diameter about one-quarter that of vesicle. No operculum observed. Delicate, transparent, peripheral membrane may be supported locally by distal parts of processes.

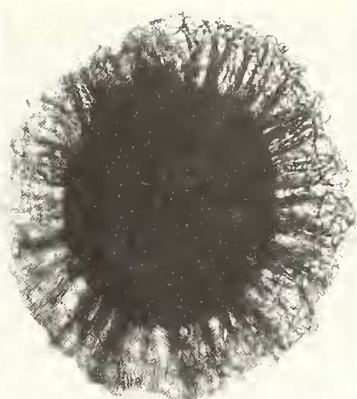
EXPLANATION OF PLATE 14

Figs. 1 and 2. *Aryballomorpha grootaertii* (Martin) comb. nov. et emend., M. and Y. slide 2; ER-32; antapical view,  $\times 500$ . 1, O-39-2; 2, O-38-1.

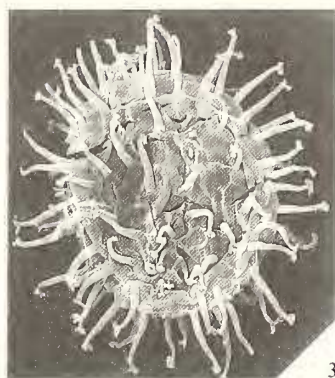
Figs. 3–8. *Athabascaella penika* sp. nov. 3, M. and Y. slide 11, N-43-1; MUX-10,  $\times 1000$ . 4 and 5, holotype, M. and Y. slide 3, M-32; ER-32. 4, enlargement of left part of 5,  $\times 2000$ ; 5,  $\times 1000$ . 6 and 8, M. and Y. slide 2, O-37-4; ER-32. 6, opposite face of gold-coated specimen of 8,  $\times 500$ ; 8,  $\times 1000$ . Transparent peripheral membrane locally preserved in upper half. 7, M. and Y. slide 5, D-38-1; ER-3,  $\times 500$ .



1



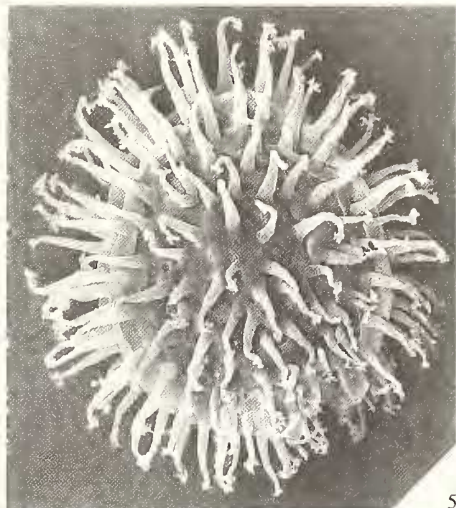
2



3



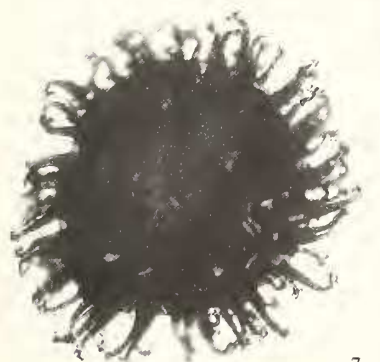
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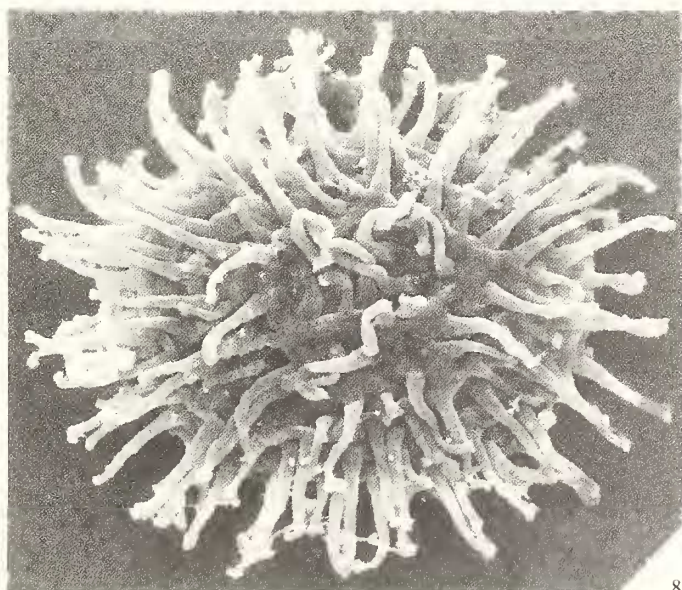
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*Dimensions* (based on fifty specimens). Diameter of vesicle: 35 (45) 65  $\mu\text{m}$ ; length and basal width of trunks of processes: 6.0–15.0  $\mu\text{m}$  and 1.5–2.5  $\mu\text{m}$ ; length of subdivisions from first to fourth order: up to 9.0  $\mu\text{m}$ ; thickness of vesicle wall: about 0.3  $\mu\text{m}$  maximum.

*Discussion.* See Martin (1984, p. 446) and discussion of emended generic diagnosis herein.

*Athabascaella rossii* Martin, 1984 emend.

Plate 15, figs. 1–6

v\* 1984 *Athabascaella rossii* Martin, p. 446, pl. 58.2, figs. 5–12.

*Type horizon.* Tremadoc of Alberta, Canada, between trilobite letter zones D and E in terms of zonal succession established in Utah and Nevada, USA.

*Emended diagnosis* (based on 120 Chinese specimens). Vesicle globular, with circular outline and apparently single-walled. Evenly distributed on each face are about 100–150 short processes, proximal parts of which were originally hollow, their interiors communicating with that of vesicle. Proximal part (= trunk) of each process more or less cylindrical to slightly conical or diaboloid-shaped; base narrow and length between one-sixteenth and one-seventh, usually one-tenth, diameter of vesicle. Locally trunks have lateral expansions joining adjacent processes. Distal part of each process with two to four short subdivisions of first order which are in turn subdivided, generally up to fourth order. Terminations variably widened and rounded. Surface of both vesicle and processes smooth or weakly granulate. Pylome, rarely seen, has diameter one-fifth to one-quarter that of vesicle. No operculum observed. Delicate, transparent, peripheral membrane, supported by distal parts of processes, may surround microfossil completely.

*Dimensions* (based on fifty specimens). Diameter of vesicle: 30 (47.5) 64  $\mu\text{m}$ ; length and basal width of trunk of processes: 3.0–6.5  $\mu\text{m}$  and 1.0–2.0  $\mu\text{m}$ ; length of distal subdivisions up to fourth order: up to 1.5  $\mu\text{m}$ ; vesicle wall thickness: less than 0.3  $\mu\text{m}$ .

*Discussion.* See Martin (1984, p. 446) and emended diagnosis of genus herein. Peripheral membrane rarely almost completely preserved (Pl. 15, figs. 3, 4, 6). When the membrane is absent, an opening is very rarely observed.

Genus LUA gen. nov.

*Type species.* *Lua erdaopuziana* sp. nov., here designated.

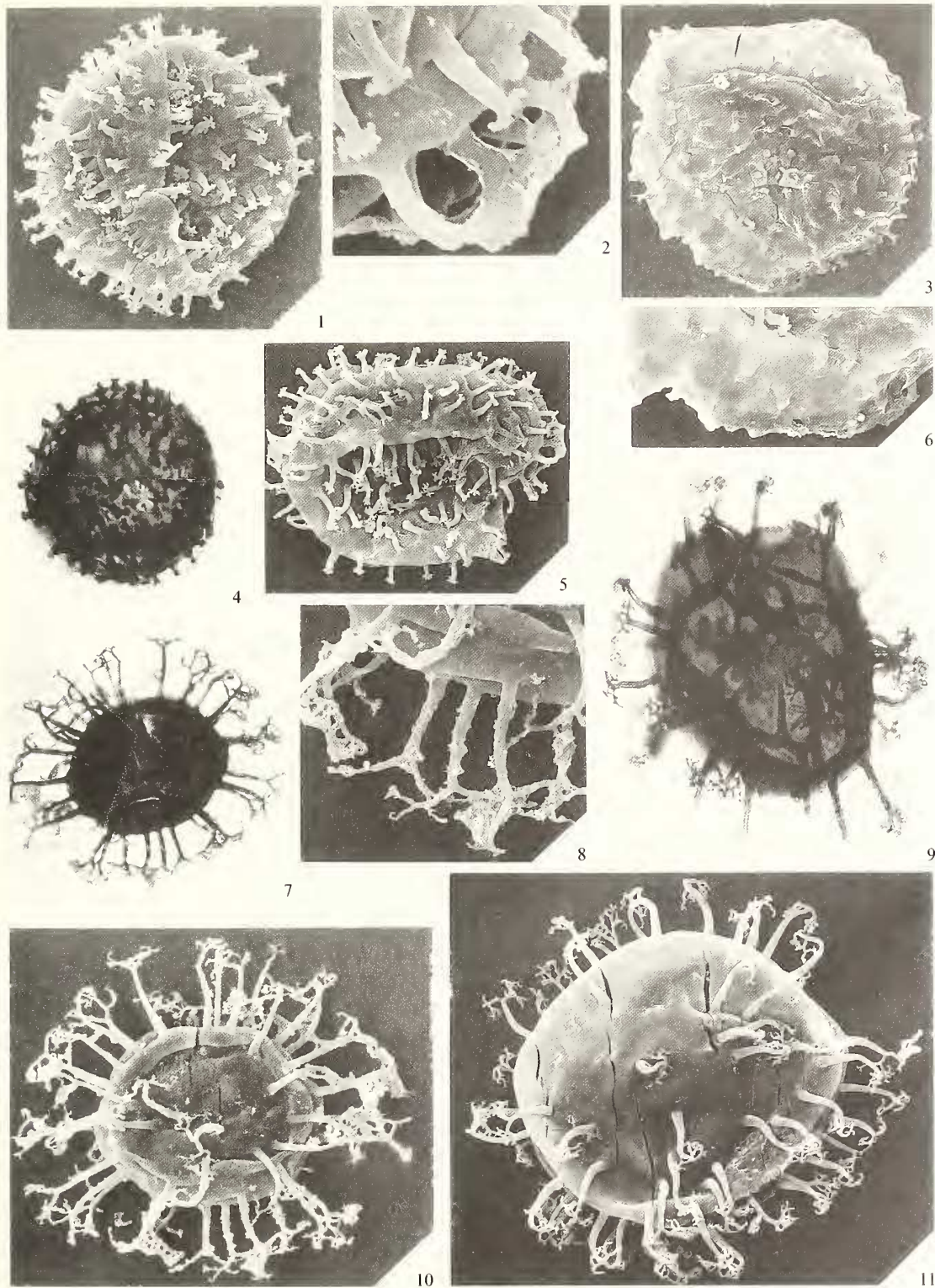
*Etymology.* Professor Lu Yenhao, Nanjing Institute of Geology and Palaeontology.

*Diagnosis.* Vesicle globular in both polar and lateral views, and apparently single-walled. Oriented laterally, some specimens show a prominent, apical, tubular extension with circular, distal opening. No operculum observed. External surface of vesicle and processes psilate or sculptured. Processes

EXPLANATION OF PLATE 15

Figs. 1–6. *Athabascaella rossii* Martin, 1984 emend. 1, M. and Y. slide 11, N-32-2; MUX-10,  $\times 1000$ . 2 and 5, M. and Y. slide 8, L-39-2; XIA-2. 2, enlargement of processes distally supporting fragment of peripheral membrane in middle right part of 5; one process broken longitudinally shows hollow internal cavity,  $\times 5000$ ; 5,  $\times 1000$ . 3 and 6, M. and Y. slide 11, N-33-1; MUX-10. 3,  $\times 1000$ ; 6, enlargement of lower part of 3 with peripheral membrane surrounding processes and vesicle,  $\times 2000$ . 4, M. and Y. slide 1, V-54; ER-32,  $\times 750$ . Figs. 7–11. *A. playfordii* Martin, 1984 emend. 7, 8, 10, M. and Y. slide 2, P-38-1; ER-32. 7, opposite face of gold-coated specimen of 10,  $\times 500$ ; 8, enlargement of processes in lower part of 10, transparent peripheral membrane locally preserved in lower half,  $\times 1500$ ; 10,  $\times 750$ . 9, M. and Y. slide 6, C-32-4; ER-3,  $\times 1000$ . 11, M. and Y. slide 11, N-33-1; MUX-10,  $\times 1000$ .





very numerous, hollow, with interior assumed to have communicated originally with that of vesicle. Processes are heteromorphic, simple or, most often, subdivided distally to form discrete tips; they are evenly distributed on vesicle and absent from tubular extension.

*Comparisons.* *Lua* differs from *Aryballomorpha* gen. nov. in having shorter, more variably shaped processes that do not anastomose distally to form a surrounding meshwork. It is distinguished from *Aremoricanium* Deunff, 1955 by having processes that are both more numerous and more subdivided, and from *Axisphaeridium* Eisenack, 1967 by the lack of any obvious difference between the thickness of the vesicle wall and that of the tubular extension (versus the pylome), and by the absence of a pseudopylome.

*Lua erdaopuziana* sp. nov.

Plate 16, figs. 1-6

*Etymology.* Erdaopuzi, place name of the type locality.

*Type locality and horizon.* Erdaopuzi section, Jilin Province, north-east China; second *Psigraptus* level (Tremadoc Series) in 'Yehli Formation'; sample ER-32.

*Holotype.* NIGPAS, M. and Y. slide 2, P-38-4. Vesicle slightly compressed, more or less spherical, 54-64  $\mu\text{m}$  in diameter; length and basal width of tubular extension: 10 and 20  $\mu\text{m}$ ; length and basal width of trunks of processes: 4-7  $\mu\text{m}$  and 1-3  $\mu\text{m}$ ; length of distal subdivisions: up to 4  $\mu\text{m}$ ; height of echinate ornamentation on vesicle wall: up to 2  $\mu\text{m}$ .

*Diagnosis* (based on 200 specimens). Vesicle originally spherical, or almost so, and apparently single-walled; outline circular to subcircular in both polar and lateral views. Oriented laterally, some specimens show distinct, apical tubular extension with circular distal opening. No operculum observed. Length and basal diameter of tubular extension usually, and respectively, between one-seventh and one-fifth and between one-quarter and one-third of diameter of vesicle. All external surface of vesicle and tubular extension is variably but relatively strongly echinate. Numerous (at least a hundred on each face) relatively short heteromorphic processes evenly distributed over all surfaces except that of tubular extension, which tends to exhibit fine longitudinal folds along which spines are aligned. Processes normally more or less cylindrical to slightly conical, but may be variably inflated on a single specimen. Variably developed spines, generally stronger from mid-length onwards, deform irregularly the trunks of processes, length of which varies from one-thirteenth to one-fifth of diameter of vesicle. Processes hollow from their proximal to their distal parts, and interior is assumed to have communicated originally with vesicle cavity. Tips either simple and acuminate, or divided up to second order or, more often, three to five pronged.

*Dimensions* (based on seventy specimens). Diameter of vesicle: 40 (55) 74  $\mu\text{m}$ . Length and basal width of tubular extension: 8.0-12.0  $\mu\text{m}$  and 12.0-22.0  $\mu\text{m}$ ; length and basal width of trunk of processes: 4.0-9.0  $\mu\text{m}$

EXPLANATION OF PLATE 16

Figs. 1-6. *Lua erdaopuziana* gen. et sp. nov. 1 and 2, holotype, M. and Y. slide 2, P-38-4; ER-32. 1, enlargement of upper part of 2, below tubular extension,  $\times 5000$ ; 2,  $\times 1000$ . 3, M. and Y. slide 1, D-40-4, ER-32,  $\times 750$ . 4, M. and Y. slide 5, F-54-3; ER-3; spinose tubular extension,  $\times 1000$ . 5, M. and Y. slide 11, D-54-2; ER-32,  $\times 750$ . 6, M. and Y. slide 3, K-42; ER-32,  $\times 1000$ .

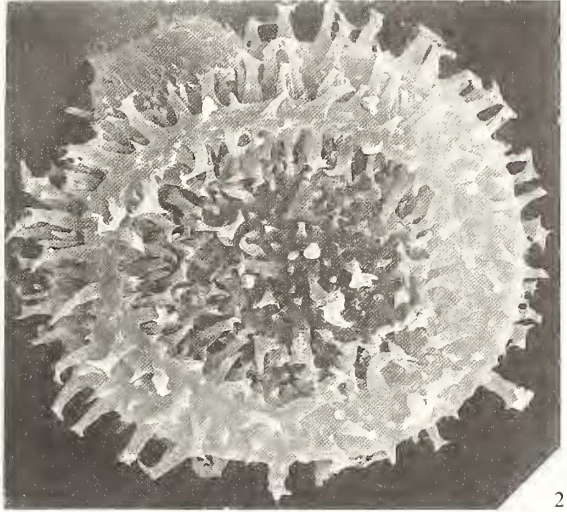
Figs. 7, 8, 10. *Rhopaliophora* cf. *R. palmata* (Combaz and Peniguel) emend. Playford and Martin, 1984. 7, M. and Y. slide 10, K-40-2; XIA-4,  $\times 750$ . 8, M. and Y. slide 7, D-36-4; XIA-2,  $\times 500$ . 10, M. and Y. slide 10, K-50; XIA-4,  $\times 750$ .

Figs. 9, 11, 12. *R. pilata* (Combaz and Peniguel) emend. Playford and Martin, 1984. 9 and 12, M. and Y. slide 10, K-40; XIA-4. 9,  $\times 1000$ ; 12, enlargement of left upper part of 9,  $\times 5000$ . 11, M. and Y. slide 9, M-30-2; XIA-34,  $\times 1000$ .





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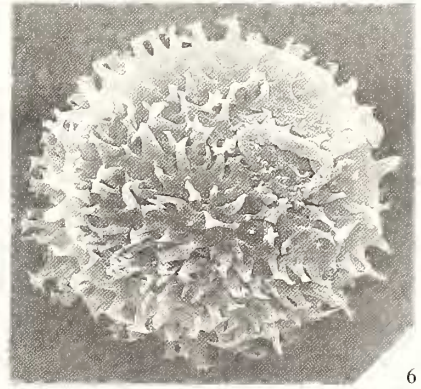
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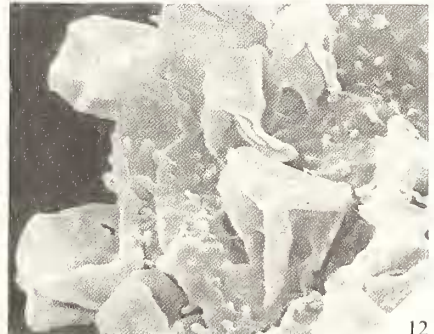
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11



12



and 1.0–3.0  $\mu\text{m}$ ; length of distal divisions is up to 5.0  $\mu\text{m}$  and that of spines is up to 3.7  $\mu\text{m}$ ; maximum height of echinate ornamentation: 2.0  $\mu\text{m}$ ; vesicle wall thickness: 0.2–0.3  $\mu\text{m}$ .

*Discussion.* Because of its dense ornamentation the wall of the vesicle is generally darker than that of the processes. Only in the relatively rare transparent specimens can it be observed that the internal cavity of the peripherally located processes communicates with that of the vesicle, and that the wall of the latter is of approximately the same thickness as the wall of the processes. Most often the echinate ornamentation of the external surface is abraded on the tubular extension, which consequently appears scabrate. In apical view the tubular extension is in most cases seen to be compressed (Pl. 16, fig. 6) and is visible clearly only under the SEM. The external wall sculpture and the shape and greater number of processes distinguish *L. erdaopuziana* from *Aremoricanium decoratum* Loeblich and MacAdam, 1971 which, according to its authors, occurs in the Mountain Lake Member (?Llandeilo or early Caradoc) of the Bromide Formation in Oklahoma, USA.

Genus RHOPALIPHORA Tappan and Loeblich, 1971 emend. Playford and Martin, 1984

*Type species* (by original designation). *Rhopaliophora foliatis* Tappan and Loeblich, 1971.

*Rhopaliophora* cf. *R. palmata* (Combaz and Peniguel) emend. Playford and Martin, 1984

Plate 16, figs. 7, 8, 10

1987 *Rhopaliophora membrana* Li Jun, p. 621, pl. 71, figs. 1 and 3.

*Description* (based on sixty specimens). Vesicle originally globular with circular outline; vesicle wall psilate, apparently single-layered. Approximately sixty, originally homomorphic processes evenly distributed on each face; they are hollow, with interior separated from that of vesicle by latter's wall. Basically prismatic in cross-section, with four or five sides, processes are most often very irregularly tubular and variably inflated, with base slightly narrower than tip. Their length varies from one-tenth to one-half vesicle diameter, and the extremely fine wall is often lacerated, with the shreds flattened upon each other. One pylome, rarely observed, is always compressed and lacks lip-like rim. No operculum observed.

*Dimensions* (based on twenty specimens). Diameter of vesicle: 35 (51) 68  $\mu\text{m}$ ; length of processes: 9.0–26.0  $\mu\text{m}$ ; thickness of vesicle wall: 0.3–0.5  $\mu\text{m}$ .

*Discussion.* *R.* cf. *R. palmata* is identical with equally poorly preserved lower Arenig examples from the Meitan Formation, Tongzi County, Guizhou Province, China, that Li Juan (1987) attributes to *Rhopaliophora membrana* sp. nov. The specimens differ from *R. palmata* as described by Playford and Martin (1984, p. 210) from the Ordovician (Arenig, Llanvirn, ?Llandeilo) of Western Australia in having the processes generally more swollen and the vesicle surface always without ornamentation.

*Rhopaliophora pilata* (Combaz and Peniguel) emend. Playford and Martin, 1984

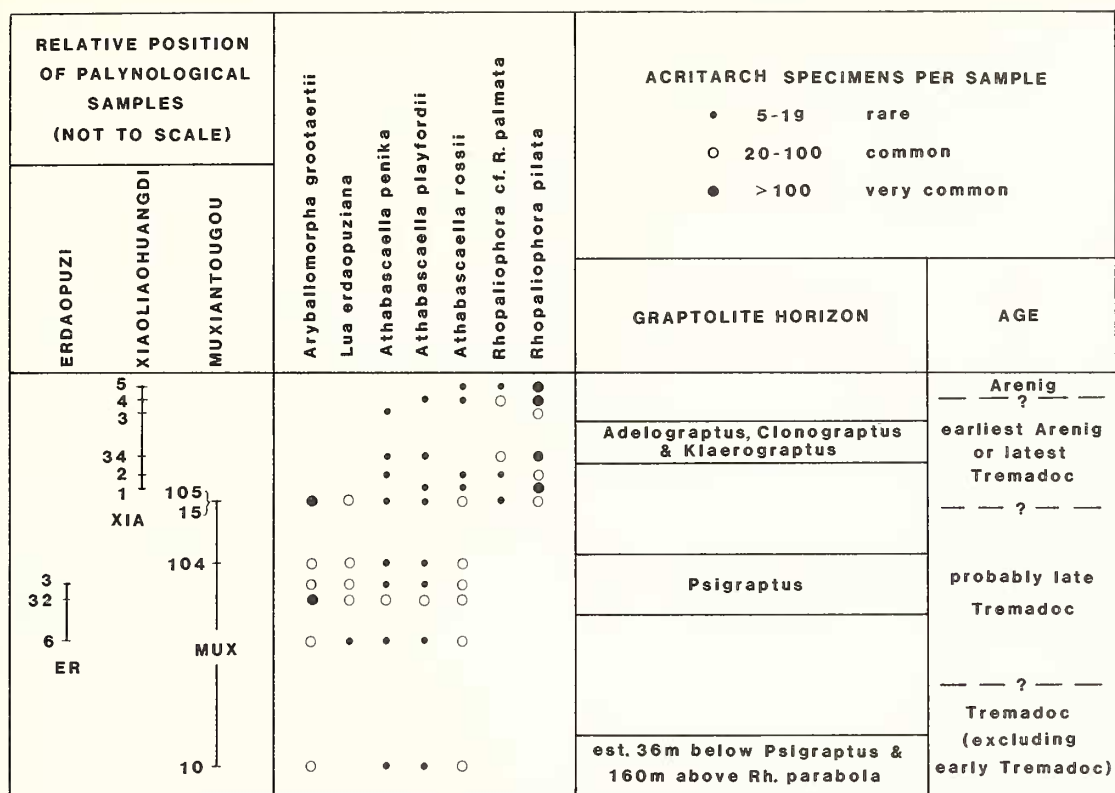
Plate 16, figs. 9, 11, 12

1972 *Peteinosphaeridium pilatum* Combaz and Peniguel, p. 136, pl. 2, figs. 1–3.

pp. 1972 *Leiosphaeridia* cf. *wenlockia* Downie, 1959; Combaz and Peniguel, p. 128, pl. 1, fig. 5.

v 1984 *Rhopaliophora pilata* (Combaz and Peniguel) comb. nov. et emend.; Playford and Martin, p. 212, fig. 10A–E, G–M.

*Description* (based on 150 specimens). Vesicle originally globular with circular outline. Vesicle wall single-layered, psilate or, rarely, echinate to pilate. On each face about fifty to, more often, one hundred processes, distribution, shape, and appearance of which match those in emended diagnosis. Their length, approximately equal to their width, between one-twelfth and one-tenth diameter of vesicle. One or, more rarely, two pylomes without lip-like rim sometimes observed, their diameter from about one-sixth to one-quarter that of vesicle. Eight of ten opercula examined are entirely psilate; the other two, partially displaced into vesicle cavity, show respectively three and five transparent processes of same type as those on central body.



TEXT-FIG. 2. Acritarch distribution at Erdaopuzi, Xiaoliaohuangdi, and Muxiantougou sections.

*Dimensions* (based on eighty specimens). Vesicle diameter: 22 (45) 64  $\mu\text{m}$ ; length of processes: 2.0–7.0  $\mu\text{m}$ ; vesicle wall thickness: 0.3–0.5  $\mu\text{m}$ .

*Discussion.* Playford and Martin (1984) showed that in the Ordovician assemblages from Western Australia the variation of *R. palmata* overlaps with that of *R. pilata*, the latter species being distinguished from the former by its more numerous, shorter processes and by the invariably psilate external surface of the vesicle.

Although the specimens from Jilin Province sometimes show a scabrate to pilate ornamentation and, contrary to the original generic diagnosis, processes on the operculum were observed in 20% of cases, nevertheless they are attributed to *R. pilata* because of their large number of processes. The length of the latter is more constant than in the Australian specimens and is closer to the limit of variability between the two species.

#### STRATIGRAPHIC AND PALAEOGEOGRAPHICAL SIGNIFICANCE OF THE ACRITARCHS

Bearing in mind the limitations of the present sampling, the most significant change in distribution of the acritarchs (text-fig. 2) appears to occur at the youngest level sampled at Muxiantougou (samples MUX-15 and MUX-105), 5.5 m below the first *Adelograptus*–*Clonograptus*, with *Kiaerograptus*, horizon. *Arybalломорpha grootaertii* and *L. erdaopuziana* were not found above this level, but *R. pilata* and *R. cf. R. palmata* enter and continue higher. A tentative limit between a probably late Tremadoc

age and a latest Tremadoc or earliest Arenig age is consequently proposed at the level where *Rhopaliophora* appears.

(a) *Aryballomorpha grootaertii*

Common in every sample from levels in or near the probably late Tremadoc *Psigraptus* horizons at Erdaopuzi, it is common also at Muxiantougou from about 36.0 m below the previous graptolite index level attributed to the Tremadoc (excluding early Tremadoc) to 5.5 m below the *Adelograptus-Clonograptus*, with *Kiaerograptus*, horizon, which is of latest Tremadoc or earliest Arenig age.

Preliminary investigations in the southern Canadian Rocky Mountains, Alberta, indicate that *Aryballomorpha grootaertii* is variably abundant (Martin 1984) in the middle member of the Survey Peak Formation: these rocks formed part of Laurentia and their trilobites do not exhibit any clear affinities with those of north-east China (Zhou and Fortey 1986; W. T. Dean, pers. comm.). No graptolites have been recorded from these strata, which were assigned (Dean in Dean and Martin 1982) to trilobite letter zones D and E, proposed by Ross (1949, 1951) in the Tremadoc of Utah and Nevada, USA. Ross *et al.* (1982) correlated zones D and E with approximately the middle part of the *Adelograptus tenellus-A. humnebergensis* fauna. According to Cooper (1979, p. 17) these two species occur in the Tremadoc Series of Shropshire, in the Transition Beds and in the overlying *A. tenellus* Biozone. The top of this fauna is succeeded (Ross *et al.* 1982) by the *Tetragraptus approximatus* Biozone, which conventionally marks the base of the Arenig Series in Great Britain, although its presence in the type Arenig area has not been proved (Fortey in Whittington *et al.* 1984, p. 21). According to Ross *et al.* (1982) letter zones D and E are equated in the Tremadoc with the uppermost part of the *Cordylodus angulatus* Biozone and the lowermost part of the *Paltodus (Drepanoistodus) deltifer* Biozone, in terms of the North Atlantic conodont biozones.

(b) *Lua erdaopuziana*

Usually common at Erdaopuzi and Muxiantougou in deposits in or near the *Psigraptus* horizons, at the former section it appears 5.8 m below the first of these horizons. At the latter section it is recognized from the *Psigraptus* horizon up to 5.5 m below the first *Adelograptus-Clonograptus*, with *Kiaerograptus*, horizon. Like *Athabascaella penika*, it is at present unknown elsewhere and both species are provisionally considered to be endemic to the northern border of the Sino-Korean platform from, probably, late Tremadoc to earliest Arenig.

(c) *Athabascaella penika*, *A. playfordii*, and *A. rossii*

All three are often present, though in variable abundance, at Erdaopuzi, Xiaoliaohuangdi, and Muxiantougou. At the last-named locality their lowest occurrence is 36.0 m below the *Psigraptus* level; their highest record is 10.0 cm to 2.0 m above the *Adelograptus-Clonograptus*, with *Kiaerograptus*, horizon at Xiaoliaohuangdi.

*Athabascaella playfordii* and *A. rossii*, together with *Aryballomorpha grootaertii*, are known (Martin 1984) from the middle member of the Survey Peak Formation in Alberta, in strata without macrofossils located between letter zones D and E.

(d) *Rhopaliophora pilata* and *R. cf. R. palmata*

*R. pilata* is common at a level 5.5 m below the *Adelograptus-Clonograptus*, with *Kiaerograptus*, horizon at Muxiantougou; at Xiaoliaohuangdi it occurs in abundance from 3.0 m below the same graptolite horizon to 2.0 m above it. In the same samples from both sections *R. cf. R. palmata* is abundant or rare; its apparent scarcity may be due to selective destruction of the very delicate processes.

In the Canning Basin, Western Australia (Combaz and Peniguel 1972; Playford and Martin 1984), *R. pilata* and *R. palmata* are usually common in the Willara, Goldwyer, and Nita formations; they are unrecorded below the upper Arenig but extend into the Llanvirn (or ?Llandeilo).

Specimens identical with *R. cf. R. palmata* are present (Li, 1987; Martin, pers. obs.) in the Meitan Formation in northern Guizhou Province, south-west China, strata that formed part of the Yangtze



Platform (Huang *et al.* 1977) and are correlated with the upper part of the *Didymograptus extensus* Biozone, lower Arenig. Zhou and Fortey (1986, p. 169) emphasized that the greatest similarity between the trilobite faunas of the Sino-Korean and Yangtze platforms occurred in the Tremadoc and ended after the beginning of the Arenig.

Rare fragments of chitinozoans found in all samples from Xiaoliaohuangdi, including that (XIA-1) from 3.0 m below the *Adelograptus*–*Clonograptus*, with *Kiaerograptus*, horizon, do not at present provide any evidence for defining a boundary between probably late Tremadoc and latest Tremadoc or earliest Arenig deposits in the Hunjiang area.

This group is absent from the Tremadoc of Quebec, Canada (Achab 1986), reported rarely from the Tremadoc in the Sahara (Combaz 1968; Poumot 1968), perhaps present in the Tremadoc of the Russian Platform (Umnova 1969), and is found in Hunneberg strata in Estonia (Grahn 1984). It appears to be particularly characteristic from the Arenig onwards, but this may reflect the greater number of papers devoted to Arenig and younger chitinozoans.

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